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SOLUTION TO THERMAL COMFORT USING FUZZY LOGIC

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ABSTRACT

Two objectives of thermal comfort and energy saving are heating, ventilation and air conditioning (HVAC) systems. Thermal comfort cannot be attained by a controller, as it impacted by temperature, relative humidity, air velocity, environment radiation, activity level and cloth insulation. Hence, a fuzzy logic concept was used to measure the thermal comfort level, but this measure is based on the air temperature, the mean radiant temperature, the relative humidity, the air velocity, the activity level of occupants and their clothing insulation. Sensation index of the fuzzy logic is obtained as a result of linguistic rules that render human's comfort level because of the interaction of the environmental variables and the occupant's personal parameters. This concept is based on Fanger's 'Predicted Mean Vote'_PMV.equation. However, the new fuzzy PMV calculation, which is the controller feedback, is dependent on iterative solution and is capable of adapting easily with regard to users' specific thermal sensation, making it an attractive index for HVAC systems' feedback control. Of the two fuzzy controllers are developed, one with temperature as its feedback and the other with the PMV index as its feedback. It has been demonstrated that the PMV feedback controller seems to have a better control of the thermal comfort and energy consumption compared to the system with temperature feedback.

KEYWORDS: Thermal Comfort, PMV, Automobile Cabin, Fuzzy Controller & Energy

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Original Article

1. INTRODUCTION

In automobiles, temperature always played a chief role in traffic accidents [1]. Thermal comfort can be evolved with the aid of a better climate control system in automobiles, and this leads to increased driver caution and therefore improved driving performance and safety in various driving conditions, minimizing energy consumption.

A cooling system's compressor functions by the automobile engine, which in turn elevates the fuel consumption. With the appropriate skills and experience, the system can be controlled manually, but if automated the driver can be freed from its control.

According to Zhong et al. [8], the general fuzzy controller and the state feedback with weighting fuzzy controller are the two used for managing the temperature of indoor air of a car. Through experiments, it has been proved that the state feedback with weighting fuzzy controller is more potent than the other in controlling the automobile indoor air temperature.

These days fuzzy PMV is implemented, rather than Fanger's PMV. PMV index demonstrates thermal comfort and its variables are quite simple. Because of its simplicity in usage, the comfort level can be arrived at when the inside cabin temperature and air velocity are comprehended. Two fuzzy controllers are developed, one with a temperature feedback and another with a PMV feedback, which also provides an energy consumption index.

Minimal energy consumption is achieved with a controller having PMV feedback.

2. THERMAL COMFORT

Providing comfort in all conditions is the elemental objective of HVAC. Fanger introduced the thermal comfort equation [19,20].

2.1. PMV

Alteration in environmental, such as air temperature, mean radiant temperature, air velocity and relative humidity, and personal factors, such as activity level and clothing insulation, inside the cabin provides thermal comfort. With regard to the six thermal variables, the Fanger's PMV presents the appropriate thermal comfort. Equation (1) as derived by Fanger's PMV.

$$\begin{aligned}\mathrm{PMV} = {} & (0.028 + 0.3033 e^{-0.036M}) \cdot \{(M - W) \\ & - 3.05[5.733 - 0.000699(M - W) - \mathrm{Pa}] \\ & - 0.42[(M - W)] - 0.0173M(5.867 - \mathrm{Pa}) \\ & - 0.0014M(34 - T_a) - 3.96 \cdot 10^{-8}\mathrm{fcl}[(T_{cl} + 273)^4 \\ & - (T_{mrt} + 273)^4] - \mathrm{fcl} \cdot h_c(T_{cl} - T_a)\}, \qquad (1)\end{aligned}$$

$$\begin{aligned}T_{cl} = {} & 35.7 - 0.028(M - W) \\ & - 0.155 I_{cl}\{3.96 \cdot 10^{-8}\mathrm{fcl}[(T_{cl} + 273)^4 - (T_{mrt} + 273)^4] \\ & - \mathrm{fcl} \cdot h_c(T_{cl} - T_a)\}, \qquad (2)\end{aligned}$$

The parameters are as follows,

PMV: predicted mean vote.

M: metabolism (W/m2).

W: external work, equal to zero for most activity (W/ m2).

Icl: thermal resistance of clothing (Clo).

fcl: ratio of body's surface area when fully clothed to body's surface area when nude.

Ta: air temperature (^{0}C).

Tmrt: mean radiant temperature (^{0}C).

Vair: relative air velocity (m/s).

Pa: partial water vapor pressure (kPa).

hc: convection heat transfer coefficient (W/m2 k)

Tcl: surface temperature of clothing ()^{0}C.

2.2. Fuzzy Thermal Sensation Index

The issues faced in designing a modern industrial HVAC system are guaranteeing thermal comfort of dwellers and decreasing energy consumption. To develop an HVAC control system with excellent thermal comfort and energy efficiency ensures high performance and good robustness by varying the environmental variables and the activity level of the dwellers and their clothing insulation. It becomes a challenge to develop an HVAC system approach that manage the

thermal comfort levels because of the non-linear thermal sensation of the humans and the nonavailability of a direct quantitative PMV.

This problem can overpowered by deriving the thermal sensation index as a consequence of the six previously mentioned variables impacting the thermal sensation of humans. Fuzzy PMV was based on fuzzy logic theory, which was converted into rules and functions. The basic concept involved converting all combinations of the variables impacting thermal comfort into linguistic fuzzy implications so that the thermal sensation index can be obtained. The input–output relationships are converted into fixed fuzzy rules. The human thermal sensation is analyzed using the state of six input variables. A PMV value can be determined by certain linguistic rules such as:

IF the air temperature (*T*a) is *High*,

AND the relative humidity (RH).is around 50%, AND relative air velocity (V_{air}). is *Very small*,

AND radiant mean temperature (T_{mrt}).is *Close to* air temperature, AND the activity level (MADu). is *Low*, AND the clothing (I_{c1}).is *Very light*, THEN PMV is *Near* zero (the indoor climate is comfortable).

Although fuzzy terms are used to define the six input variables, the abovementioned framework needs a higher number of fuzzy rules and thus a large amount of time. Assuming that fuzzy PMV model consists of two subsystems, this rule numbers can be significantly decreased: the personal-dependent model and the environmental model, whose interaction is shown in Figure 1. The personal-dependent model estimates the air temperature range, which in turn is measured based on the occupants' activity level and their clothing insulation. The environmental model measures the PMV with regard to *T* and the four environmental variables.

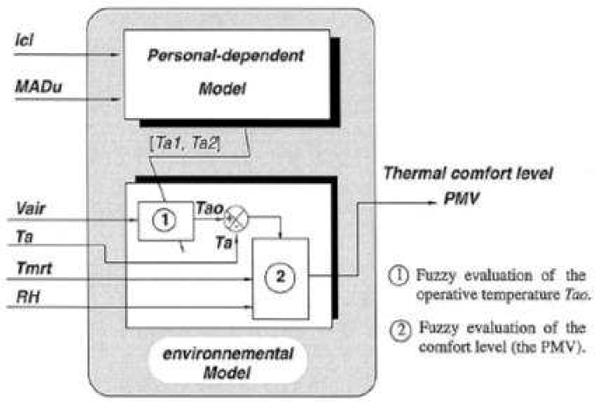


Figure 1

2.3. The Fuzzy PMV Calculation

The fuzzy thermal sensation index concept follows a four-step process. In the first step, the input and output variables of the personal-dependent subsystem are decided. As shown in Figure 1, the input variables include the occupants' activity level and their clothing insulation. and its output variable includes the ambient temperature range with a predicted mean vote is close to zero. However, inputs variables of the environmental-dependent subsystem are air temperature *T*., air velocity Vair, mean radiant temperature *Tmrt*, and relative air humidity RH. Its corresponding output variable includes the predicted mean vote value (fuzzy PMV). The second step involves extraploating the fuzzy rule base to measure the PMV, which is only based on the input variables. Wang and Mendel [17] used Fanger's thermal sensation vote equation to invoke an accurate fuzzy rule. As shown in Figure b, fuzzy rules are derived by all possible six-variable

combinations, dividing the input and the output spaces into symmetric triangular membership functions.

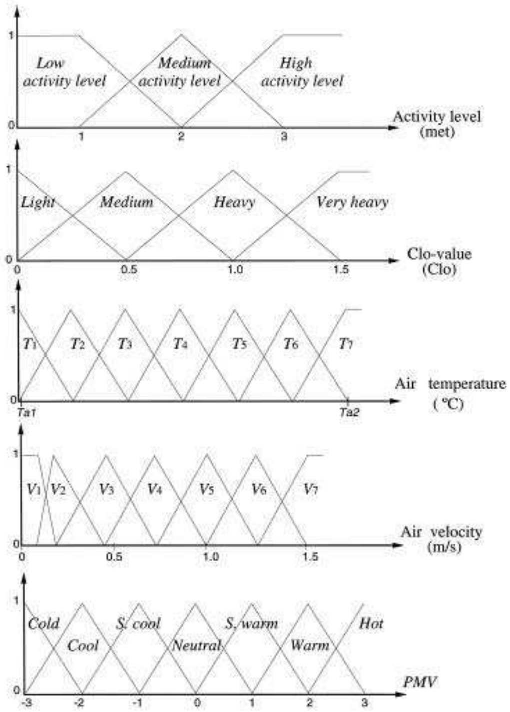


Figure 2: Initial Membership Functions

2.4. The Personal-Dependent Model Rules

The input variables are mainly subject to the personal-dependent variables and the environmental variables. The variation in *Icl* and MADu influences the heat production in the body and consequently, the mean temperature of the outer surface of the clothed body (*T*cl). The air temperature range provides thermal comfort is measured with the relative influence of the activity level and the clothing insulation. The fuzzy logic uses three- and five-membership functions, respectively, to determine the activity level and the clothing insulation. This is linguistically expressed as follows

IF the occupant has *Light* clothing AND he or she is sedentary

THEN the ambient temperature should be *Very high* (in [28.28^0–31.58] ^{0}C range)

IF the occupant has *Medium* clothing AND his or her activity level is *Medium*

THEN the ambient temperature should be *normal* (in [19.5^{0}C –23.5^{0}C] range) IF the occupant has *Very heavy* clothing AND his or her activity level is *Medium*

THEN the ambient temperature should be *low* (in [10.8^{0}C –14^{0}C] range)

2.5. The Environmental Model Rules

The personal-dependent model is considered to adapt the environmental model by measuring the air velocity to derive the operative temperature that assures a predicted mean vote of zero. To achieve this, seven membership functions are used to arrive at the state of both the air velocity *Vair* and the air operative temperature *To*, generating a maximum of seven fuzzy rules as listed below,

IF the air velocity is *V1*, THEN the operative temperature is *T* 1

IF the air velocity is *V2*, THEN the operative temperature is *T* 3

IF the air velocity is *V7*, THEN the operative temperature is *T*7 etc.

Where *V1*,..., *V* 7 and *T1*,..., *T7*. represent, respectively, the air velocity and the operative temperature corresponding to an optimal thermal sensation. The desired ambient air temperature is compared with the measured air temperature *Ta*. to describe the state of the predicted mean vote PMV as a fuzzy result of the following three linguistic rules:

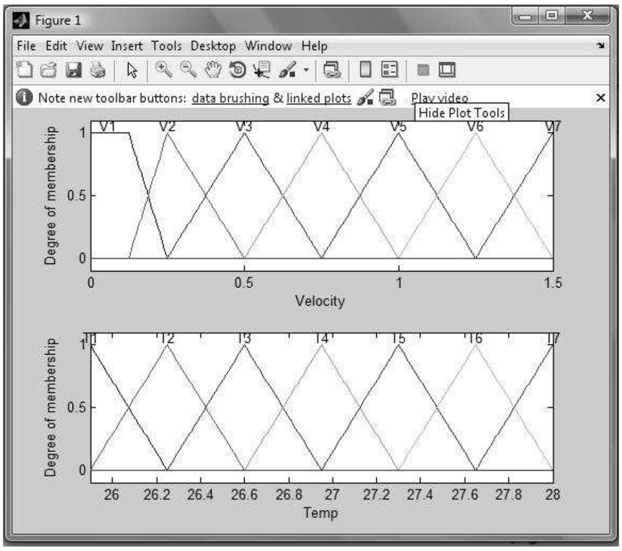
If RH=50% and Tmrt=*T*, then:

IF *T*a is *close* to *T*ao THEN the PMV is *zero*

IF *T*a is *higher than Tao* THEN PMV is *positive*

IF *Ta* is *lower than Tao* THEN PMV is *negative*.

Matlab interfaced with LabVIEW is used to measure Fuzzy PMV.



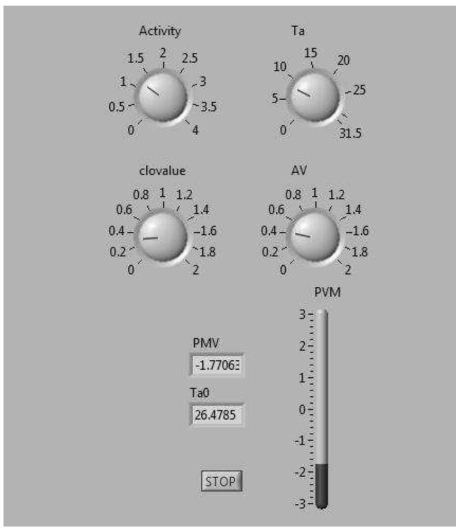


Table 1: Fuzzy PMV in LabVIEW

Activity	Cloth Value	Vair	PMV
0.5	0.4	0.2	-0.59
1	0.5	0.6	-0.398
2	1.2	0.4	0.24
3.5	2	1.8	2

3. THERMAL MODELING OF AUTOMOBILE CABIN

To obtain thermal environment mathematical model for an automobile cabin, Peugeot 206 automobile-specific measures are used. The model includes blower, evaporator, heater core as well as the impact of important thermal loads such as sun radiation, outside air temperature and passengers on climate control of cabin. Figure 1 demonstrates a schematic model. The blower power(bp) and the temperature door's (ptd) position are the chief variables. The blower power governs the blower speed and the temperature door's position governs the required blend of hot and cold air.

Blower Model

In order for the blower to be essential, it is necessary to understand the relation between blower power, air velocity and air flow rate, which are obtained experimentally for Peugeot 206 automobile. Air velocity meter, model DO2003 with probe AP471S from Delta OHM was used.

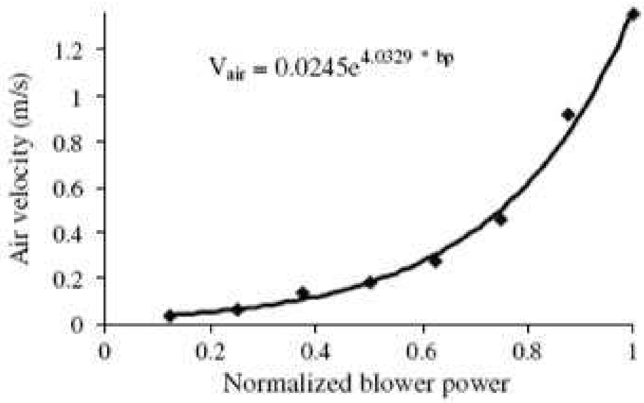


Figure 3: Mean Air Velocity versus Blower Speed

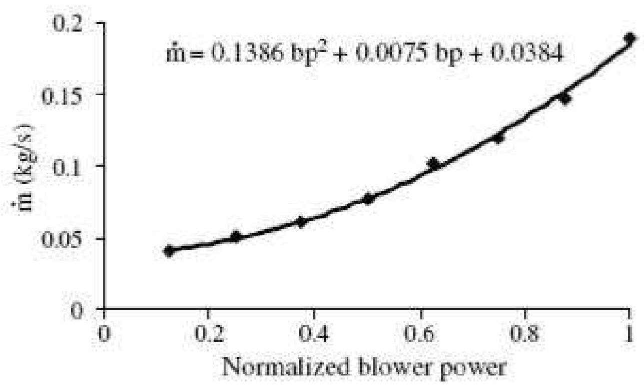


Figure 4: Mass Flow Rate versus Blower Speed

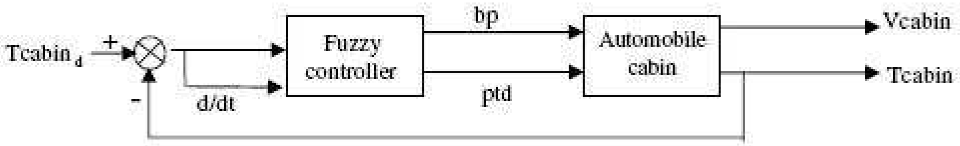


Figure 5: Temperature Control with Temperature Feedback

4. FUZZY CONTROLLER

The AC in an automobile is nonlinear and complex. Hence, controlling it conventionally is almost difficult [6]. Therefore, it can be concluded that fuzzy control is apt in controlling this system.

4.1. Fuzzy Controller with Temperature Feedback

In air conditions, temperature is used as feedback and a fix temperature as the controller goal. Figure 5 is the block diagram of this controller in the automobile cabin. Fuzzy controller's inputs are the error and the changes of error. Outputs are blower power and the position of temperature door, which govern the needed blend of hot and cold air. Error is defined by the following equation.

error= T_d-T_{cabin}

The automobile driver adjusts the desired temperature, which is generally about 22°C. The fuzzy controller's design depends on the formation of suitable fuzzy sets for which triangular fuzzy sets are considered (Figure 2).

Considering an outside temperature of 35°C and zero fresh air entering the system, simulation is achieved. It is understood that the hot soak is completed and the initial cabin temperature is equal to the outside temperature. The desired temperature in the cabin can be obtained when the controller regulates the outputs. Figure 5 is the fuzzy controller with temperature feedback.

With the simplified PMV index, the thermal comfort is measured. As Figure 5 shows, the controller obtains the desired temperature, but it cannot achieve the zero PMV as shown in Figure 6.

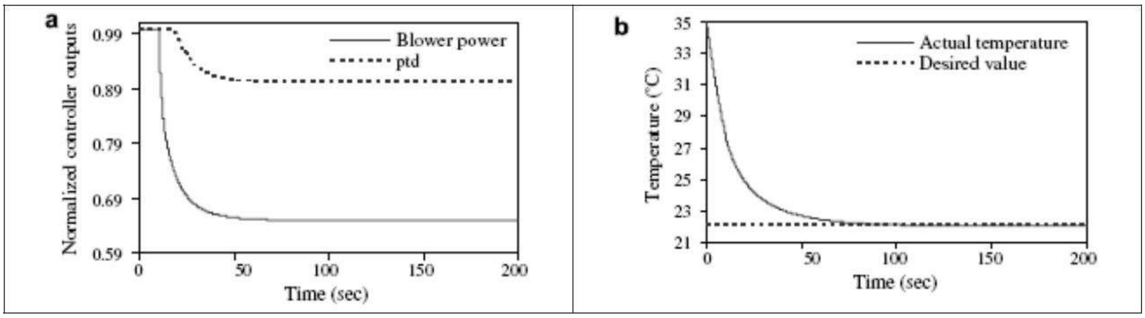


Figure 6: (a) Normalized Controller Outputs and (b) Temperature Variation in Cabin

4.2. Fuzzy Controller with Thermal Comfort Feedback

As mentioned previously, thermal comfort is not dependent on the temperature, that is, temperature feedback controller cannot provide the desired comfort. Instead a controller with PMV feedback is the apt solution (Figure 7).

The condition is considered comfort only when the desired PMV is zero. Table 1 presents the intervals for variables.

Figure 6(a) demonstrates the controller outputs, and Figure 6(b) shows the temperature and PMV comparison of two controllers.

It has been proved that the PMV has a better controls over comfort than temperature.

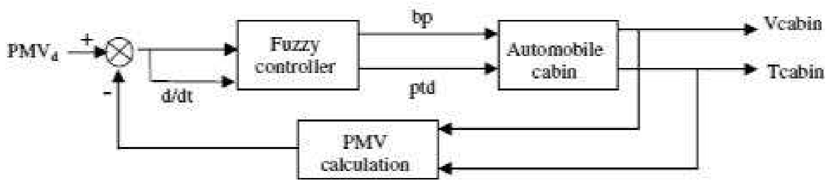


Figure 7: Controller with PMV Feedback

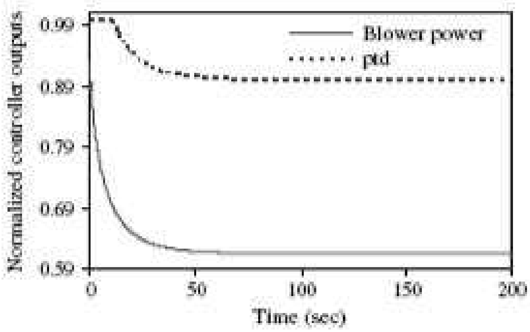


Figure 8: Normalized Controller Outputs

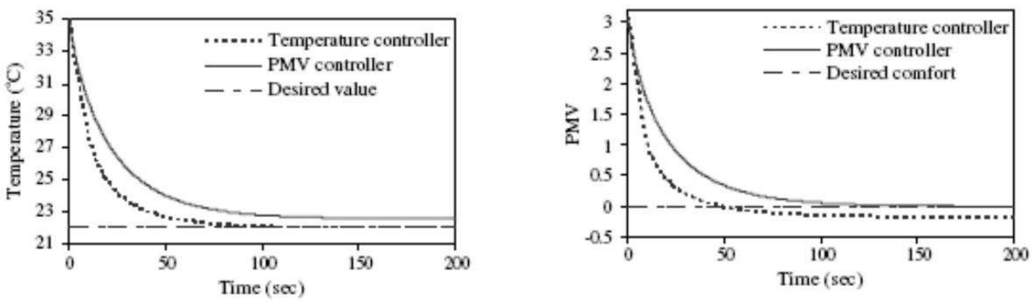


Figure 9: PMV and Temperature Variations

5. CONCLUSIONS

When there are only two variables - cabin air temperature and the air velocity - a simplified PMV can be obtained, which is achieved using fuzzy logic. In a fuzzy controller, the PMV(fuzzy) index is used as the feedback and not temperature. It can be concluded that PMV controller has a better control over comfort compared to temperature.

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